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A New Interface Circuit for High-Value Wide-Range Resistive Chemical Sensor Dynamic Characterization

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Abstract

Metal oxide (MOX) gas sensors, as well as the new nanowire-based sensors, can show resistive values varying over a wide range and could have the baseline value up to tens of gigohms. Some interface circuits use Resistance-to-Time Conversion (RTC) schemes to ensure a good resolution over the whole range. Such solutions suffer from a variable measuring time, which can become very long with high-value resistances. However, especially for the dynamic experimental characterization of new sensors, a fast and constant measuring time is required. The proposed solution merges an RTC scheme with the use of an Analog-to-Digital Converter (ADC), together with a Least Mean Square processing method, to provide a fast measurement of the sensor resistance and parasitic capacitance. The implemented prototype, based on a low-cost 12-bit ADC, allows the sensor resistance estimation with 100 sample/s (T_{meas}=10ms) over the range 10kΩ÷10GΩ with relative estimation error below 10% (below 1% in the range 47kΩ÷2GΩ). Fast thermal transients of a SnO_2 nanowire sensor have been finely analyzed thanks to the new interface system.

Keywords: wide-range sensors ; high-value resistances, nanowire sensors, fast readout circuit

1. Introduction

Metal Oxide gas sensors behaviour, in terms of equivalent resistance R_{sens} and parasitic capacitance C_{sens}, should be finely characterized as a function of gas amount, interfering quantities, thermal profile and so on. A static characterization can be provided by using traditional and expensive instrumentation (picoammeters) or suitably-designed interface circuits, based either on a high-resolution ADC or adopting a Resistance-to-Time Conversion (RTC) scheme [1]-[6].

A dynamic characterization of the sensor can be however advisable or required when new experimental devices, such as nanowire-based sensors are under consideration [7]-[8]. In addition, recent works concerning the sensor transient behaviour, during non-usual heating pulses, lead to interesting results in terms of measure robustness and sensor reliability [9]-[11]. A picoammeter-based solution is unsuitable for a fast transient analysis, because of the long measuring time which leads to a rough characterization of the sensor response. In addition, the high cost and

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size limit the use of such instrumentation as a laboratory equipment, impeding the realization of compact and portable systems. Solutions adopting an ADC require a scaling factor change system, if the whole range of resistance variation needs to be covered with sufficient resolution; for this reason, such architectures can require a difficult and expensive calibration procedure. In addition, both the aforementioned approaches adopt a constant voltage sensor supply; hence, the sensor parasitic capacitance is not excited and cannot be estimated. The use of RTC schemes allow the realization of simple interfaces which do not need particular calibration procedure, keeping low the cost of the overall system. Moreover, by using particular architectures, the parasitic capacitive component of the sensor can be estimated as well. However, in such circuits, the measuring time directly depends on the measured resistance and therefore a non-constant sampling time is obtained. Furthermore, if the sensor resistance value is very high, on the order of tens of gigohms, the measuring time can be on the order of tens of seconds, impeding a good characterization of transients.

2. The proposed system

The proposed approach is a smart evolution of the RTC-based circuit described in [2], whose principle scheme and timing diagram are shown in Fig. 1.

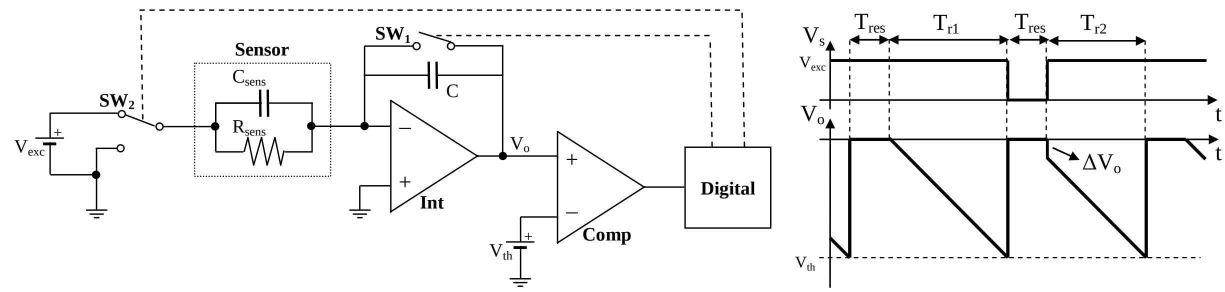

Fig. 1. (a) scheme of the original RTC circuit; (b) timing diagram related to the original RTC circuit.

The sensor is powered with a constant voltage V_{exc} and the ramp generator is reset by the switch SW_1 for a well-known time T_{res}. By measuring the time T_{r1}, the resistive value R_{sens} can be estimated by Eq. 1. The parasitic capacitive component can be stimulated by means of the switch SW_2 which causes a rapid change of V_{exc}, as visible in the second measuring cycle of Fig. 1(a). A quick step ΔV_o of the integrator output V_o is determined by the charge transfer effect, thus reducing the ramp time T_{r2}. Under the hypothesis that the resistive component do not change during the two measuring cycles, the quantity ΔV_o can be derived from the difference between T_{r1} and T_{r2} and the capacitive component C_{sens} can be estimated by Eq. 2.

$$R_{sens} = V_{exc}T_{r1} / (V_{th}C) \qquad (1)$$

$$C_{sens} = \Delta V_o C / V_{exc} \qquad (2)$$

The new proposed circuit overcomes the limits of the previous one: long measuring time with high-value sensor resistance, and critical switch SW_1 implementation (leakage, reset circuit to provide a “true” zero on the reset phase). The proposed solution adds an ADC to sample the integrator output during both the reset phase (R_0) and the normal ramp operation, as shown in Fig. 2 (a). The R_0 estimation allows to simplify the project of the switch SW_1, because this value can be used to compensate errors in the T_{r1} measurement due to a non-perfect zero on V_o. If the sensor resistance value is not so high, the original circuit can provide the R_{sens} and C_{sens} values within the imposed measuring time T_{meas}. On the other hand, if the resistance value is such that the threshold value V_{th} cannot be reached within T_{meas}, ($T_r > T_{meas}$), then the the R_{sens} and C_{sens} values can be estimated using a simple interpolation algorithm starting from the samples acquired. In fact, as visible in Fig. 2 (b), starting from N samples taken with a sample time

T_s, the Leas Mean Square (LMS) first degree fitting method can provide the slope value α and offset β of the V_o ramp within the measuring time T_{meas}, if $T_sN < T_{meas}$. Once α and β have been computed, the Rsens and Csens values can be reckoned by means of Eq. 3 and Eq. 4 respectively. In such a way, the integrator can be reset and a new measuring cycle can start, leading to a constant and short measuring time system.

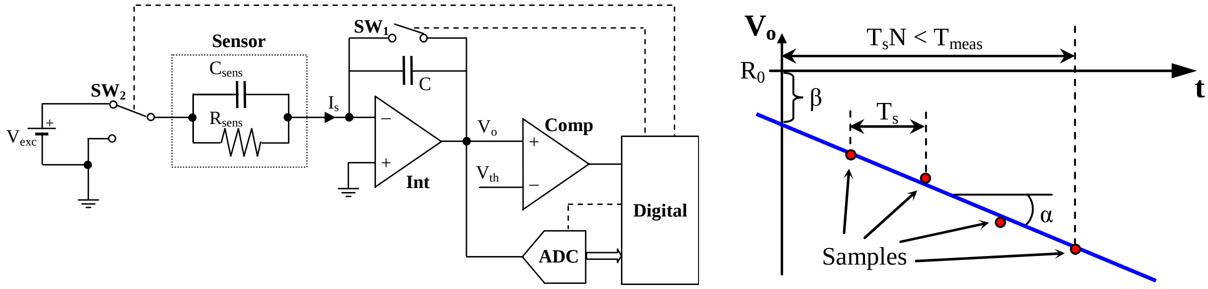

Fig. 2. (a) scheme of the proposed system; (b) working principle of the LMS interpolation algorithm applied to the integrator output.

$$R_{sens} = V_{exc} / (|\alpha|C) \tag{3}$$

$$C_{sens} = |\beta|C / V_{exc} \tag{4}$$

3. Experimental

A prototype has been realized to prove the feasibility of the proposed method. A National acquisition board (NI-6110, 12 bit of resolution) has been used together with a modified (simplified) realization of the original circuit. The synchronization between the ADC and the RTC circuit is ensured by the digital system (FPGA) which implements time measuring circuits (50 ns of resolution) and an RS232 serial link to a PC. The proposed solution, configured with a measuring time of 10ms, has been tested with commercial resistors (10kΩ-50GΩ) and to dynamically characterize a SnO_2 nanowire sensor during a thermal transient. The system characterization is summarized in Table 1. The first three columns show the RTC results (mean value, standard deviation -std-, relative error with respect to the "true" value), whereas the second block is related to the LMS method computed over 100 samples and in the third block only 8 samples are used for the LMS calculus. As visible in the table, the upper limit for the RTC method applicability is about 10MΩ; with higher resistances value, the LMS method is used. Performances of the proposed system, in terms of linearity relative error, are on the order of 1% in the range from 47kΩ to 2GΩ. For higher resistances values, performances can be improved using for example a 16-bit ADC.

Table 1. Experimental results with commercial resistors emulating the sensor.

Rsens "true" [MΩ]	RTC mean [MΩ]	RTC std [%]	RTC error [%]	LMS100 mean [MΩ]	LMS100 std [%]	LMS100 error [%]	LMS8 mean [MΩ]	LMS8 std [%]	LMS8 std [%]
0.0102	0.0110	0.00	8.20						
0.0996	0.1005	0.02	0.92						
0.9998	1.0022	0.01	0.24						
9.9690	9.9931	0.01	0.24	10.075	0.01	1.06	10.072	0.02	1.04
100				100.85	0.06	0.85	100.89	0.24	0.89
1000				1009.3	0.51	0.93	1017.7	1.97	1.77
10000				9338.7	4.84	-6.61	10597	39.66	5.97
20000				16561	8.56	-17.19			
50000				34030	22.40	-31.94			

Response of a SnO_2 nanowire-based sensor to a fast thermal transient (a quick change of the power issued to the heater) is shown in Fig. 3(a). The zoom in Fig. 3(b) highlights the fine dynamic characterization and the readout continuity although the method change at about 10MΩ of resistance value.

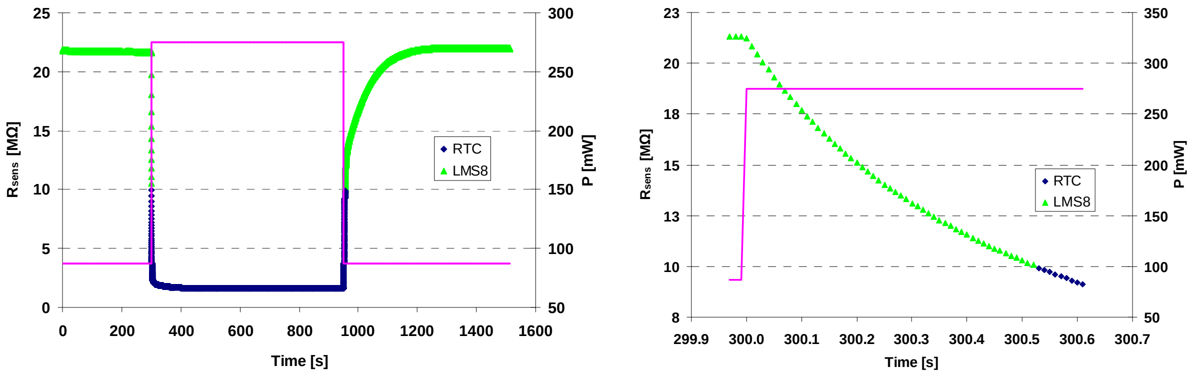

Fig. 3. (a) fast transient of a $Sn0_2$ nanowire-based sensor acquired with the proposed system; (b) zoom of the fast transient.

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References

1. Flammini A, Marioli D, Taroni A. A low-cost interface to high value resistive sensors varying over a wide range. *IEEE Transactions on Instrumentation and Measurement* 2004; **53**: 1052–6.

2. Depari A, Flammini A, Marioli D, Rosa S, Taroni A. A low cost circuit for high value resistive sensors varying over a wide range. *IOP Measurement Science and Technology* 2006; **17**: 353-8.

3. De Marcellis A, Depari A, Ferri G, Flammini A, Marioli D, Taroni A, et al. Uncalibrated integrable wide-range single-supply portable interface for resistance and parasitic capacitance determination. *Sensors and Actuators B: Chemical* 2008; **132**: pp. 477-484.

4. Falconi C, Martinelli E, Di Natale C, D'Amico A, Malcovati P, Baschirotto A, et al. Electronic interfaces. *Sensors and Actuators B: Chemical* 2007; **121**: 295-329.

5. Frey U, Graf M, Taschini S, Kirstein K-U, Hierlemann A. Digital systems architecture to accommodate wide range resistance changes of metal oxide sensors. *Proceeding of IEEE Sensors* 2008; 593-5.

6. Lombardi A, Bruno L, Grassi M, Malcovati P, Capone S, Francioso L, et al. Integrated Read Out and Temperature Control Interface with Digital I/O for a Gas-Sensing System Based on a SnO_2 Microhotplate Thin Film Gas Sensor. *Proceeding of IEEE Sensors* 2008; 596-9.

7. Sberveglieri G, Baratto C, Comini E, Faglia G, Ferroni M, Ponzoni A, et al. Synthesis and characterization of semiconducting nanowires for gas sensing. *Sensors and Actuators B: Chemical* 2007; **121**: 3-17.

8. Kuchibhatla Satyanarayana VNT, Karakoti AS, Bera D, Seal S. One dimensional nanostructured materials. *Progress in materials science* 2007; **52**: 699-913.

9. Bicelli S, Depari A, Faglia G, Flammini A, Fort A, Mugnaini M, et al. Model and experimental characterization of dynamic behavior of low-power carbon monoxide MOX sensors operated with pulsed temperature profiles. *IEEE Transactions on Instrumentation and Measurement* 2009; **58**: 1324-1332.

10. Depari A, Faglia G, Flammini A, Fort A, Mugnaini M, Ponzoni A, et al. CO detection by MOX sensors exploiting their dynamic behaviour. *Proceeding of Eurosensors XXII* 2008; 1070-3.

11. Fort A, Mugnaini M, Rocchi S, Vignoli V, Depari A, Flammini A, et al. Behavior of MOX CO sensors during thermal transients. *Proceeding of IEEE Sensors* 2008; 851-4.